ON THE PATH TO DECARBONISATION

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Cement and concrete are the fundamental building materials of the modern built environment. Our cities grow to the sky and into the ground, all based on concrete and its key ingredient, cement. Concretes are changing, but the role of concrete in our world is not. At present, most concrete has significant embodied CO_2, but there is growing focus on changing that.

In 2006, I ended my academic career as an experimental geochemist and transitioned to a role at the global technical centre for one of the world's largest cement companies. I became an expert in the chemistry and mineralogy of the clinker- and cement-making processes. I spent much time in various places around the world troubleshooting factory issues, training teams, and working on novel cements and production methods. In 2012, I left the technical centre and started on a journey within the business side of the industry, having the opportunity initially to lead a concrete division and now today being responsible for a cement business.

Concrete and the cement that goes into it are truly fascinating materials. So many disciplines come together to make their magic: geologists and their kin enjoy the quarries we develop, chemists and mineralogists excite in the high-temperature process and laboratory work we employ, engineers marvel at the machinery able to churn out millions of tonnes of material, accountants enjoy cost accounting, and even marketeers happily gnaw on the challenge to brand a grey monolith! However, the focus of this *Perspective* piece is narrow and more sinister: CO_2. After safety, my industry is globally circled around a single critical goal: decarbonisation.

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The metaphor 'the elephant in the room', describing a large, obvious, and critical situation that nonetheless no one seems to talk about, would accurately describe our industry's view of CO_2 until recent years. At the moment, however, all major cement-producing companies are communicating loudly about their ambitions to reach Net Zero by 2050 and to take action to immediately reduce their footprints. The elephant is most definitely being talked about now. Our heads are no longer in the sand, we know we have a problem, and we need help to solve it.

Concrete is a CO_2 intense product primarily because the cement going into it is CO_2 intense. As described in detail in this issue, traditional cement is manufactured predominantly by driving CO_2 out of limestone using heat primarily generated by fossil fuels. In other words, it is the perfect recipe for high CO_2 emissions per tonne of product.

We tend to chop up our CO_2 footprint into Scope 1 (our own direct emissions), Scope 2 (emissions for creating the energy we use, mostly electricity), and Scope 3 (emissions up and down the supply chain). While these different scopes help identify more directly to what extent we execute control over certain pieces of the CO_2 footprint, they also remind us that, although we are predominantly focused on the CO_2 emitted from our factories, there is a wider system in place and emissions within the supply chain that we cannot ignore.

We also tend to look at specific emissions per unit, such as how much CO_2 is released per tonne of cement, rather than total absolute CO_2 emissions. This view is debated, as increased overall production of a lower-CO_2 cement may show an opposite trend depending on the metric. Both can be useful contingent on the context. Fortunately, when both numbers are zero, the debate becomes irrelevant.

Today, we are on the path to zero CO_2. It is clear that this journey will not end overnight, but rather will require the ongoing quiet grind of both incremental improvements and local novel solutions that will spread over time. Innovations will occur across the value chain, including those directly within the manufacturers' traditional control (production efficiency, binder/cement types) as well as those more often external (electricity generation, construction and design efficiency, national standards, carbon capture and utilisation/storage). The pieces of the puzzle are quite well known, but their sizes and shapes are under development. Countless small start-ups are moving fast and trying new things, many with direct support from my own team.

Over many years, the evolution of cement has shown improvements driven by efficiency. While CO_2 has been reduced, this was previously always of secondary importance and driven especially through plant modernisations, growth of alternative fuel sources, and development of alternative cementitious materials—all from a cost-improvement perspective. In concrete, the same situation of efficiency-led improvements is the key to success, particularly concrete mix designs favouring cement reduction (as cement is a costly component). These developments will continue since efficiency-related cost savings will always be advantageous in a competitive market. The recent shift is that CO_2 has rapidly grown to such a level of importance that it now rivals financial performance. This shift has been significantly driven both by the new environmental, social, and governance focus of stakeholders (including investors) as well as the implementation of CO_2 cost schemes in various jurisdictions. Simply put, a business previously reliant on no-cost CO_2 externalities can no longer assume this to continue to be the case in perpetuity and strong improvements are needed to maintain our informal, but powerful, 'licence to operate'—the general acceptance of society that we offer more benefits than costs and should continue to provide these benefits.

Sustainability requires profitability. For the cement and concrete industry to continue to develop on a path to zero CO_2 requires significant investment and, therefore, demands the outlook of a viable and profitable business. While we develop technical solutions to carbon, we must also develop commercially viable solutions for customers. Concrete is used so widely today because it provides quality and usefulness unmatched at its cost. At present, many customers are interested in lower-CO_2 options, but only so long as cost is not increased relative to traditional materials. This paradigm is actively being resolved from two directions: first, CO_2 credit schemes are increasing the cost of higher-CO_2 products and, second, lower-CO_2 technology is improving and making these products more viable. Additionally, there is a small but growing pull effect from the final users of construction for more sustainable options. When home buyers, for example, demand (and are willing to pay for) lower-CO_2 housing, home builders will be willing to build with more sustainable materials at potentially higher cost. It is clear that there is a value to reduced-CO_2 offerings, but at the moment, that value does not yet translate into dollars and cents. Hopefully, this will change in the near-term.

I am a strong believer in economics driving behaviour, and one of the fascinating developments in the modern industrial era is the initiation of these various CO_2 credit schemes around the world. While complicated in detail, the ambition to attach a cost to CO_2 emission has

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wonderful consequences. Cement has always operated within classic industrial economics, which means there are high fixed costs for large production facilities (e.g., salaries) and variable costs per tonne (e.g., raw materials) for incremental production. Typically, once enough volume is sold to cover the fixed costs, profitability escalates substantially, hence maximisation of productive assets is highly incentivised. However, with CO_2 credits required to be purchased above a certain threshold, these economics can be reversed and the final tonne produced can become the most expensive, not the cheapest, to produce. This turns the dynamic upside down, forcing incremental sale volumes to be more costly, thus incentivising lower CO_2. This changes fundamentally which products should be produced and at what price they should be sold, especially as free CO_2 allocations decrease and credits increase in cost.

With the CO_2 intensity of traditional cement, one would expect other materials to readily substitute; however, building materials globally are constrained by mass balance: what is voluminous enough to be used to create the built environment? Calcium oxide and silica are fortunately very common in Earth's crust and have the rare ability, at relatively low cost, to be transformed into a hydraulic binder. Concrete based on this binder has impressive working properties and incredible durability, along with a huge existing infrastructure put in place for its production, delivery, and use. At the moment, alternatives to cement and concrete are a combination of being very localised, difficult to work with, expensive, and lacking either strength or longevity.

Here, I should elaborate that concrete is not only a material but also an ecosystem enabling construction. There is a large logistics network behind the supply of the physical quantities of material, a vast established network of engineers and architects able to use concrete creatively and safely, and every city has thousands of trained people familiar with and competent to place concrete. There are complaints that our industry moves too slowly, and to some extent this is true because there is a risk aversion as the cost of risk can be quite high—ask yourself: 'Am I comfortable building my home with a material that the engineer has not used before and constructed by a contractor unfamiliar with it?' In the majority of our applications, tolerance for failure is zero, but need for innovation is vast; a paradigm we must balance.

Alternative binders, the so-called supplementary cementitious materials (SCM), are already supporting the decarbonisation of concretes. Unfortunately, it seems unlikely that a complete solution with SCM is possible. The main materials in use today globally are fly ash (a by-product of coal-fired electricity generation) and iron slag (a by-product of iron production). Both of these materials are typically much less effective in generating early strength in concrete, a critical parameter, and both are dependent on industries that are actively reducing these by-products in the name of climate change. While other SCM, including natural materials, offer significant local opportunities, in a global context, high transportation effort would be required, and these come with CO_2 concerns as well. Nevertheless, SCM will continue to play a strong role in reducing the need for traditional cement, with availability and quality continuing to put a ceiling on global conversion.

Notwithstanding the improvements in cement and concrete that we make, the future is a world of quality and circularity. We need to build our environment robustly so that it lasts and can be refurbished instead of replaced. When we do replace our constructed areas, they need to be ready to be deconvoluted in such a way that the pieces can be reused in value-added ways and not discarded. For example, we may pour a concrete foundation for a home that will last 100 years. When the home eventually is to be replaced, the concrete in the foundation can be recovered to create fresh materials, for example, by crushing and reuse in fresh concrete to make a new 100-year-lasting home. In this context, we must also, as a society, become more hesitant to replace things that still have usable life; fashion and style can have a hefty CO_2 footprint! We must do more with the total life cycle concept. Here again, a balance must be achieved as we are at a critical moment in time and CO_2 savings many years away will not help us reach our goal in a timely manner. At the same time, installations with much longer functional lives can have a dramatic positive impact overall, for example, compare a bridge needing replacement after 100 as opposed to 50 years.

I work in a terribly exciting industry with hardworking people passionate about making, moving, and selling things that we can reach out and touch. I think about a project to build a bridge that might link my town to the city my daughter may live in one day or the apartment building where my son will one day fall in love. Cement and concrete quietly support our lives in a literally foundational way. We have an enormous challenge to meet with CO_2 reduction, but with a worldwide focus and intelligent people making fantastic innovations, I believe we will reach zero CO_2.

The future will be a combination of innovations to maintain and enhance our living conditions through both better building materials and better building with no CO_2 footprint. A large place remains for cementitious binders and the concretes based on these binders for many years into the future. Concrete will continue to be a key construction material as we progress to lower CO_2 levels in the near-years, as well as on the mid-term when we reach Net Zero, and in the long-term when we pass that goal.

One of the beautiful things about the number zero is its indivisibility. Once we are at zero, there are no incremental reductions, one cannot double or halve it. It does not matter if one discusses specific emissions per tonne or total emissions; it really is a special number. A number we will reach.

ABOUT THE AUTHOR

Andrew J. Stewart has been Vice President at Lafarge Eastern Canada since 2020 after holding various management and technical roles within the global building material supplier over the past 15 years both in Canada and Europe. He has led cement, concrete, and aggregate divisions within Canada since 2015. Andrew is a geochemist with a PhD from ETH Zurich (Switzerland), MSc from McGill (Canada), and BSc (hon.) from the University of Toronto (Canada), as well as MBAs from the University of Toronto and University of St. Gallen (Switzerland).